Technical Reports

Smoke Application for Maximum Product Appeal

The most savage controversies are those about matters as to which there is no good evidence either way. - Bertrand Russell

Few areas of meat processing generate more discussion and contradictory advice than the smoking process. Even though a considerable amount of research has been conducted, the smoking process remains more of an art than a science. What follows is a discussion of the principles of meat smoking and basic guidelines to be used in the development of smoking processes, which will help give you a better understand the art of smoking.

Types of Smoke

Wood smoke is added to cured meat products for its desirable color, flavor, aroma, and preservative effects. The two types of smoke used for smoking meat products are vaporous smoke and liquid smoke. Both types are used extensively throughout the industry.

Vaporous Smoke

Smoke composition

Wood smoke consists of two distinct phases: the particulate phase and the gaseous phase. The particulate phase accounts for about 90% of the total volume, and contains many undesirable or unnecessary components which are not important in meat smoking. The gaseous phase contains most of the desirable components, and is essential for good smoke color and flavor.

Over 390 different compounds have been detected in wood smoke, and it has been estimated that smoke may contain over 1,000 compounds. Of these, over 70 compounds have been isolated in smoked foods. The compounds most important to meat smoking are divided into three basic categories: phenols, carbonyls, and acids.

These compounds are mostly contained in the gaseous smoke phase, and are responsible for various desirable and undesirable effects.

Desirable effects

The desirable effects of the smoking process include its influence on color, flavor, aroma, antioxidant activity, and antimicrobial activity. These desirable effects are common to both vaporous smoke and liquid smoke.
• **Smoke color.** Smoking, heating, and drying are all involved in smoked color development. The smoked color of meat products is developed when the carbonyls in the smoke are absorbed into the product surface, and then react with the amino groups in meat protein to form the desired smoked color. Although the carbonyl compounds are mainly responsible for smoked color development, the phenol compounds also contribute to color development. The color reaction between the carbonyls from the smoke and the amines in the meat is enhanced by hot, dry conditions. Even if the product is not smoked, some surface browning is also created from the reaction of amino groups with carbonyls that are naturally available in meat. This is why non-smoked products develop a brown surface color when they are exposed to dry heat, even though smoke is not applied.

The basic mechanism of smoke color formation is the same as that of a reaction known as the Maillard browning reaction. This means that, as with Maillard browning, color formation will be promoted by hot, dry conditions. This is why, after liquid smoke is applied, a hot, dry “color setting” step is used to develop and set the smoke color before proceeding with humidified cooking steps. Maximum color formation on a food surface will occur when the surface moisture content is between 6 and 10%.

• **Flavor & aroma.** Smoked meat flavor and aroma is mainly due to the phenols present in wood smoke. Over 20 different phenols contribute to smoked flavor, some of which also contribute to the aroma of smoked meat.

• **Antioxidant activity.** Smoke has a strong antioxidant activity which is associated with the phenol groups. This antioxidant activity helps to prevent the development of off-flavors due to oxidative rancidity.

• **Antimicrobial activity.** The smoking process kills bacteria and prevents their growth because of the combined effects of heating, drying, reduced pH, and antimicrobial smoke components. The phenol compounds in smoke are mainly responsible for the antimicrobial effect. The acids are responsible for the reduced pH.

**Undesirable effects**

Along with the desirable effects of smoking, there are also some undesirable effects including the degradation of some nutrients and contamination of meat products with potentially toxic compounds from the smoke. The nutrient degradation is of minor importance, and will not be further discussed.

• **Contamination with carcinogenic compounds.** The most prominent undesirable effect of smoking is the potential for product contamination with polycyclic aromatic hydrocarbons (PAH) compounds that exist in vaporous smoke. Some PAH compounds such as benzo(a)pyrene have been demonstrated to be mutagenic and carcinogenic in numerous animal experiments. Researchers have found that the contamination of product by benzo(a)pyrene is related to very high smoke generation temperatures. As a result, smoke generation temperatures of less than 600-850°F have been recommended to reduce PAH contamination of vaporous smoked products.

The PAH compounds can be removed during the production of liquid smoke, and therefore the contamination of smoked meat products with PAH compounds is not a concern for products that are liquid smoked.
Vaporous smoke application

Vaporous smoke used in smokehouses is produced using several different types of smoke generators. Many factors influence the effectiveness of vaporous smoke application, including product surface moisture content, oven temperature, relative humidity, air velocity, and smoke generator temperature.

The effects of these variables on smoke application is discussed in the following paragraphs. Some of the research concerning these factors was conducted by measuring smoke absorption into water-filled casings, and therefore may not reflect the surface drying or other actual conditions that occur during smoking. Even so, this research gives us valuable insight into the effects of these variables on smoke color development.

- **Surface moisture.** Research conducted using fish muscle has shown that smoke is absorbed more rapidly by a moist surface than by a dry surface.

  Figure 1 shows that when product having different moisture contents was smoked, the phenol absorption was higher for the product with a moist surface than for the drier product. In another study on fish muscle, researchers found that smoke absorption decreased as the product surface dried. Figure 2 shows that more smoke was absorbed in the first 20 minutes of smoking than in the remaining 100 minutes. This suggests that if you want a darker smoked color, you don't necessarily have to smoke longer, but rather just start smoking sooner. This research shows that adequate surface moisture is necessary for smoke absorption, and that increased surface moisture levels will enhance smoke absorption. However, even though adequate surface moisture is necessary for smoke absorption, keep in mind that too much surface moisture during smoking may result in an excessively dark brown or black smoked color, and may even cause streaking.

  The depth of smoke penetration into bologna smoked for four hours is illustrated in Figure 3. In this experiment, only small amounts of phenols were found to penetrate past 7/16" below the product surface. Another study reported that small amounts of phenols had penetrated to 1/2" below the surface of ham smoked for 24 hours. This shows that vaporous smoke does not penetrate very far, and is essentially confined to the product surface.

- **Oven temperature.** Figure 4 shows the amounts of smoke components that penetrated into a water-filled cellulose casing at various oven temperatures.

  As shown on the figure, the acids were apparently unaffected by changes in the oven temperature. Carbonyl absorption was increased at temperatures up to 180 degrees F, and phenol absorption increased steadily as the oven temperature was increased.

  These results imply that smoke absorption may be improved at higher oven temperatures. However, when meat is smoked instead of water-filled casings, the higher oven temperatures will dry the product surface more rapidly. If the product surface is dried too much before smoke is applied, this may actually slow down smoke absorption.
• **Relative humidity.** The influence of relative humidity on smoke absorption into water-filled cellulose casings is shown in Figure 5.

As the relative humidity was increased from 18% to 70%, the absorption of smoke components decreased. In another study, researchers found that the particulate phase of smoke was changed to a dark brown color at high relative humidities. The changes in color, concentration, and composition of the smoke itself at high relative humidities may be responsible for the muddy-brown color often seen for product smoked at high humidities.

• **Smoke generator temperature.** The smoke components absorbed by water-filled cellulose casings smoked using different smoke generator temperatures are shown in Figure 5.

As shown on the figure, the absorption of carbonyls and phenols increased substantially at higher smoke generator temperatures. Acid absorption was only slightly increased. While this evidence shows that higher smoke generator temperatures increased the available carbonyls and phenols in smoke, it should be noted that high smoke generator temperatures also create increased levels of undesirable PAH compounds.

### Liquid Smoke

Many meat processors have successfully replaced the more traditional vaporous smoking of meat products with the application of liquid smoke. Liquid smoke contains the same functional components -- phenols, carbonyls, and acids -- that are found in vaporous smoke. However, an advantage of using liquid smoke is that the undesirable PAH compounds such as benzopyrene can be removed from liquid smoke. An additional advantage of liquid smoke is that the emission of undesirable pollutants from the oven to the atmosphere is reduced.

### Liquid smoke application

Liquid smoke can be applied using several different methods:

- direct addition
- drenching or dipping
- impregnated (smoked) casings
- atomization

**Direct addition.** Liquid smoke can be added directly to cured meat products either by including it in injection brines or by incorporating it into boneless hams during tumbling or massaging. The liquid smoke that is used for this method is specially formulated for direct addition. The type of smoke used for direct addition adds smoke flavoring to the entire product (not just the surface), but does not contribute significantly to surface color formation. When liquid smoke has been added by direct
addition, it must be labeled as part of the product name and in the ingredients statement.

**Drenching or dipping.** Surface applications of liquid smoke such as drenching or dipping will contribute to surface color formation and flavor. Drenching is commonly used for the application of liquid smoke to frankfurters before entering a continuous oven. For batch ovens, a drench cabinet is sometimes used to apply liquid smoke to the product before it is loaded into batch ovens. Product treated using this method may be labeled as "smoked".

**Smoke-impregnated casings.** Application of liquid smoke using impregnated "pre-smoked" fibrous casings is a relatively new method of smoke application. Product that is stuffed into smoke-impregnated casings will develop a smoked color and flavor as the smoke in the casing is absorbed during cooking. Product treated using this method may be labeled as "smoked".

**Atomization.** Atomization is the most inefficient method of liquid smoke application, but is also the most widely used by meat processors because it is easily adapted to batch ovens. Product that has been liquid smoked using atomization may be labeled as "smoked".

The most common method of atomized liquid smoke application is the atomize/dwell method. Using this method, the product is usually dried for a period of time before smoking. The oven is then shut down and the liquid smoke is atomized into the oven. After atomization is completed, the atomized cloud is usually allowed to dwell or "rest" for a time before the oven is restarted. This atomize/dwell procedure is sometimes repeated two or three times during the process.

As a rule of thumb, if it takes longer than 30 minutes to atomize the required amount of smoke into the oven, then it may be a good idea to break a single atomization step into two or more steps. For example, if it takes 50 minutes to atomize the required amount of liquid smoke for a load of boneless hams, instead of using one long 50-minute atomization step, it will probably be more effective to use two 25-minute atomization steps separated by a 30-minute drying step.

As with any other type of smoke application, a period of dry heat is necessary after the smoke application step for proper color development. Problems with color variation that occur using the atomization method can often be resolved by shortening the dwell time or by running the main blower during the last part of the dwell time to circulate the atomized cloud. Regardless of the atomization time, dwell times of longer than 5 to 10 minutes are probably unnecessary, and long dwell may cause color variation within the oven.

Another method of atomization is to continuously atomize liquid smoke into the oven during one or more smoke cook steps, without shutting down the oven. This method is much like a traditional vaporous smoke process. Very low liquid smoke flow rates are necessary to avoid excessive consumption of smoke, and this method can make the oven more difficult to clean.
Smoked Color Development & Uniformity

Most color problems associated with smoking fall into two general categories:

1. Color uniformity problems
2. Color development problems

Either you're not getting the color that you want, or you're getting the color that you want, but not on all of the product.

Almost any question on how to improve smoked color development or uniformity will usually result in a tidal wave of contradictory advice. I will try not to add to that wave of contradictions here, but rather offer the following simple suggestions to keep in mind when developing or revising smoking processes:

1. Make sure that your smoke generator or liquid smoke application system is working properly and consistently from day-to-day. It is obviously difficult to develop a good, uniform smoked color with inadequate or inconsistent levels of smoke.
2. Start with uniform product surface conditions. Whether this is accomplished by a short, pre-cooking shower; a lengthened drying step; a low-temperature, high-humidity conditioning step; or by some other pre-smoking conditioning step, differences in pre-smoking product surface conditions must be reduced as much as possible. Non-uniform surface conditions before smoking will result in non-uniform smoked color after smoking.
3. Moisture or lack of moisture on the product surface is the most critical factor in determining smoked color. When developing or revising smoking schedules, monitor surface moisture conditions either by feel or by measuring surface temperature. The proper moisture condition for smoking will vary greatly depending on the product and casing type. In general, a moist surface favors smoke absorption and will create a darker smoked color, while a dry surface retards smoke absorption and will create a lighter smoked color. If you want a darker smoked color, you don't necessarily have to smoke longer, but rather just start smoking sooner. On the other hand, if the surface is too wet when smoke is applied, you may get an undesirable dark brown or even black color.
4. Include a dry "color setting" step immediately after the smoking step. The purpose of this step is to develop and set the smoked color before moving on to higher humidity cooking and finishing steps. Setting the color after smoking will help prevent the development of a mottled or even streaky surface appearance. A color setting step is essential after a liquid smoke application step, but is sometimes omitted from vaporous smoke processes if the color has been developed and set during the smoking step.

Conclusion

Of all the different processes involved in the manufacture of meat products, the smoking process is probably one of the least well understood, and remains more of an art than a science. Given the wide variety of smoked meat products and the large number of variables affecting smoke color, however, this lack of understanding of the smoking process should not be surprising. Even so, if you go to work armed with a good understanding of the basic principles of meat smoking and if you remember the critical impact of drying time and surface moisture on smoke color, you've got a fighting chance of making good products the first time and every time. And if things by chance do go wrong, you can quickly figure out what went wrong, and fix it right for the next time.